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ABSTRACT

This report summarizes the findings of one of fourteen panels that studied progress in space science applications and defined user needs potentially capable of being met by space-system applications. The study was requested by the National Aeronautics and Space Administration (NASA) and was conducted by the Space Applications Board. The panels comprised user specialists drawn from federal, state, and local governments and from business and industry. The Panel on Information Services and Information Processing took as its domain of concern the applications of space systems to land-use planning, agricultural resources, inland water sources, extractable resources, environmental quality, and marine resources. Among the recommendations of the panel was that the experience gained and the results achieved with earth-observation satellites now warrant increased support in several applications fields for studies and practical experiments in preparation for the design of operational systems. (MH)

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Practical Applications of Space Systems

Supporting Paper 13

Information Services and Information Processing

A Panel Report Prepared for the

Space Applications Board

Assembly of Engineering

National Research Council

SE 021 016

1974 SUMMER STUDY ON PRACTICAL APPLICATIONS OF SPACE SYSTEMS

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PRACTICAL APPLICATIONS OF SPACE SYSTEMS

Supporting Paper 13

INFORMATION SERVICES AND INFORMATION PROCESSING

The Report of the
PANEL ON INFORMATION SERVICES AND INFORMATION PROCESSING
to the
SPACE APPLICATIONS BOARD
of the
ASSEMBLY OF ENGINEERING
NATIONAL RESEARCH COUNCIL

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PREFACE

In November 1973, the National Aeronautics and Space Administration (NASA) asked the National Academy of Engineering* to conduct a summer study of future applications of space systems, with particular emphasis on practical approaches, taking into consideration socioeconomic benefits. NASA asked that the study also consider how these applications would influence or be influenced by the Space Shuttle System, the principal space transportation system of the 1980's. In December 1973, the Academy agreed to perform the study and assigned the task to the Space Applications Board (SAB).

In the summers of 1967 and 1968, the National Academy of Sciences had convened a group of eminent scientists and engineers to determine what research and development was necessary to permit the exploitation of useful applications of earth-oriented satellites. The SAB concluded that since the NAS study, operational weather and communications satellites and the successful first year of use of the experimental Earth Resources Technology Satellite had demonstrated conclusively a technological capability that could form a foundation for expanding the useful applications of space-derived information and services, and that it was now necessary to obtain, from a broad cross-section of potential users, new ideas and needs that might guide the development of future space systems for practical applications.

After discussions with NASA and other interested federal agencies, it was agreed that a major aim of the "summer study" should be to involve, and to attempt to understand the needs of, resource managers and other decision-makers who had as yet only considered space systems as experimental rather than as useful elements of major day-to-day operational information and service systems. Under the general direction of the SAB, then, a representative group of users and potential users conducted an intensive two-week study to define user needs that might be met by information or services derived from earth-orbiting satellites. This work was done in July 1974 at Snowmass, Colorado.

For the study, nine user-oriented panels were formed, comprised of present or potential public and private users, including businessmen, state and local government officials, resource managers, and other decision-makers. A number

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*Effective July 1, 1974, the National Academy of Sciences and the National Academy of Engineering reorganized the National Research Council into eight assemblies and commissions. All National Academy of Engineering program units, including the SAB, became the Assembly of Engineering.

of scientists and technologists also participated, functioning essentially as expert consultants. The assignment made to the panels included reviewing progress in space applications since the NAS study of 1968* and defining user needs potentially capable of being met by space-system applications. User specialists, drawn from federal, state and local governments and from business and industry, were impaneled in the following fields:

Panel 1: Weather and Climate
Panel 2: Uses of Communications
Panel 3: Land Use Planning
Panel 4: Agriculture, Forest, and Range
Panel 5: Inland Water Resources
Panel 6: Extractable Resources
Panel 7: Environmental Quality
Panel 8: Marine and Maritime Uses
Panel 9: Materials Processing in Space

In addition, the study the socioeconomic benefits, the influence of technology, and the interface with space transportation systems, the following panels (termed interactive panels) were convened:

Panel 10: Institutional Arrangements
Panel 11: Costs and Benefits
Panel 12: Space Transportation
Panel 13: Information Services and Information Processing
Panel 14: Technology

As a basis for their deliberations, the latter groups used needs expressed by the user panels. A substantial amount of interaction with the user panels was designed into the study plan and was found to be both desirable and necessary.

The major part of the study was accomplished by the panels. The function of the SAB was to review the work of the panels, to evaluate their findings and to derive from their work an integrated set of major conclusions and recommendations. The Board's findings, which include certain significant recommendations from the panel reports as well as more general ones arrived at by considering the work of the study as a whole, are contained in a report prepared by the Board.**

It should be emphasized that the study was not designed to make detailed assessments of all of the factors which should be considered in establishing priorities. In some cases, for example, options other than space systems for accomplishing the same objectives may need to be assessed; requirements for

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*National Research Council. *Useful Applications of Earth-Oriented Satellites, Report of the Central Review Committee*. National Academy of Sciences, Washington, D.C., 1969.

**Space Applications Board, National Research Council. *Practical Applications of Space Systems*. National Academy of Sciences, Washington, D.C., 1975.

institutional or organizational support may need to be appraised; multiple uses of systems may need to be evaluated to achieve the most efficient and economic returns. In some cases, analyses of costs and benefits will be needed. In this connection, specific cost-benefit studies were not conducted as a part of the two-week study. Recommendations for certain such analyses, however, appear in the Board's report, together with recommendations designed to provide an improved basis upon which to make cost-benefit assessments.

In sum, the study was designed to provide an opportunity for knowledgeable and experienced users, expert in their fields, to express their needs for information or services which might (or might not) be met by space systems, and to relate the present and potential capabilities of space systems to their needs. The study did not attempt to examine in detail the scientific, technical, or economic bases for the needs expressed by the users.

The SAB was impressed by the quality of the panels' work and has asked that their reports be made available as supporting documents for the Board's report. While the Board is in general accord with the panel reports, it does not necessarily endorse them in every detail.

The conclusions and recommendations of this panel report should be considered within the context of the report prepared by the Space Applications Board. The views presented in the panel report represent the general consensus of the panel. Some individual members of the panel may not agree with every conclusion or recommendation contained in the report.

PANEL ON INFORMATION SERVICES AND INFORMATION PROCESSING

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INTRODUCTION

The Panel on Information Services and Information Processing took as its domain of concern the applications of space systems to land use planning, agriculture resources, inland water resources, extractable resources, environmental quality, and marine resources. The area of materials processing in space does not, at this time, appear to require a large data processing system, so relatively little attention has been devoted to this topic. Any comments regarding data processing that are relevant and important to the subject are found in the Report of the Panel on Materials Processing in Space.* Applications to weather and climate do entail a large integrated information and data processing system. However, requirements for applications in this field are sufficiently unique, the user community is sufficiently cohesive and sophisticated, and applications have progressed sufficiently far with an evolving operational system that the Panel on Information Services and Information Processing judged it appropriate for substantially less attention to be devoted to this area than to the others listed. Comments on this subject are included in the report of the Panel on Weather and Climate.**

An earth observation system for the remaining areas listed is inherently a system for acquiring and manipulating data, extracting information from the data, and using the information as a basis for decisions related to management of earth resources and environment. Data and information and their manipulation are central and all-pervasive factors in such management so that the legitimate scope of the Panel overlaps and supports the scope of each user panel.

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*Panel on Materials Processing in Space. *Practical Applications of Space Systems; Supporting Paper 9: Materials Processing in Space.* Report to the Space Applications Board, National Research Council. National Academy of Sciences, Washington, D.C., 1975.

**Panel on Weather and Climate. *Practical Applications of Space Systems; Supporting Paper 1: Weather and Climate.* Report to the Space Applications Board, National Research Council. National Academy of Sciences, Washington, D.C., 1975.

PROGRESS SINCE 1967-68 SUMMER STUDY

ADEQUACY OF PRIOR RECOMMENDATIONS FOR PRESENT AND FUTURE NEEDS

The 1967-68 summer study recommended the implementation and operation of an experimental data acquisition space system to conduct investigations aimed at determining the capability to produce data and information for use in a wide variety of applications related to earth resources and environment. It was recommended that a program use a satellite like the first Earth Resources Technology Satellite (ERTS-1) with a first-generation data system including transmitting and receiving equipment. The system recommended consisted largely but not exclusively of such facilities for formatting and disseminating photographic data as now exist at Goddard Space Flight Center (GSFC) and at the Earth Resources Observation System (EROS) Data Center at Sioux Falls, South Dakota. A supporting aircraft program was recommended for the acquisition of related data. It was recommended in much less detail that studies of a second-generation semi-automated data system be carried out. The actions called for in the 1967-68 recommendations have been carried out by NASA, by associated government agencies, and by numerous investigators from both public and private sectors.

The experience gained in the operation of these systems, the results and conclusions from more than 300 experimental investigations, the results of studies concerning second-generation data systems, and rapid advances in data and information technologies create a climate, opportunity, and need for updating and extending these earlier recommendations to guide the program in the coming years. Furthermore, since the results of these 300 investigations have shown that data of significance to user applications can be acquired, it is now appropriate to devote substantial research and design to systems for data and information utilization. Primary space, aircraft, and data collection system (DCS) data must be merged with those from other space systems, such as meteorological satellites, and with relevant data from other sources.

RESPONSE TO PRIOR RECOMMENDATIONS

The years since the 1967-68 study, as ERTS-1 and Skylab have come into operation, have been characterized by a growing awareness, interest, and involvement in the experimental utilization of space data by users within federal,

state, and local agencies in the United States, by foreign governments, and by the private sector, including commercial organizations, universities, and individuals. In addition, private industries, nonprofit research organizations, and university personnel have turned their attention increasingly to developing techniques for formatting, disseminating and interpreting such data. Although these activities are still financed predominantly by NASA, with some support from other federal agencies, and will probably need to be so supported for some time in the future, other public and private organizations and individuals are beginning to formulate programs and have begun to apply some funding to these activities. A small but growing commercial market for the data, information, and related services has come into being as potential users have become aware of the availability and potential value of the products. Another consequence of this growing awareness is that prospective and actual users are beginning to request data, information, and services tailored to their needs.

ACCOMPLISHMENTS TO DATE IN SPACE APPLICATIONS

The most notable accomplishments to date in information services and processing have been the placing in operation of the GSFC and EROS centers for formatting, cataloging, storing, and disseminating data and the increasing utilization of these facilities by a wide spectrum of users. In addition, university, nonprofit, and commercial groups have created or are beginning to create staffs and facilities both to use the data in applications and to further the development of technologies. Furthermore, there is a growing availability of commercial equipment for the manipulation of this kind of data and information.

In agriculture, crop identification capabilities have been demonstrated by several ERTS-1 investigations. Most programs have worked with a small number of crops and have demonstrated increased classification accuracy when data available over different time intervals are considered. These inputs provide first steps in the development of crop inventories and forecasts and in the detection of crop stress, disease, and insect infestation.

In other areas, ERTS-1 imagery aided by refined computer processing has successfully demonstrated its usefulness in first-level inventorying of range land, in generating Level I*land use maps at a scale of 1:250,000, in generating photomosaics and planimetric maps at a scale of 1:1,000,000, and in making map revisions at various scales. The presence of foliage in some seasons and its absence in others have been used to aid in soil mapping and in discriminating rock types. Some ERTS-1 images have demonstrated the detectability of lineaments because of vegetative growth patterns. Still further benefits and accomplishments derived from the present earth observation system include mapping of surface water bodies as small as a few square kilometers, surveying of estuarine

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*Level I is the grossest scale in a land use classification system proposed for use with remotely-sensed information by the Department of the Interior. c.f. Anderson, James R., Hardy, Earnest E., and Roach, John T.: *A Land-Use Classification System for Use With Remote Sensor Data.* U.S. Geological Survey Circular 671 U.S. Department of the Interior, 1972.

and coastal features, monitoring of dynamic water circulation patterns, mapping of snow and ice areas, and mapping of snowline in mountainous terrain for runoff estimation.

Commercially available data processing and analysis equipment (1) is capable of simultaneous projection ranging from multispectral images for false-color renditions to complete interactive systems; (2) includes multi-color displays, data, and computer-program access by remote terminal; and (3) has software developed for image enhancement and automated data analysis. Numerous university and private-industry groups have evolved to provide mission planning, data analysis, and data integration for users at all levels of government and commerce both in the U.S. and internationally.

CURRENT USER NEEDS AND POTENTIAL BENEFITS

DEFINITION OF CURRENT USER NEEDS

Adequate expression of user needs is extremely important in obtaining maximum benefits from applications programs and optimum design for improvement of space systems and institutions. Adequate definition of user needs is extremely difficult. User needs are diverse both in types of data and information required and in the degree to which refined or even interpreted rather than raw data are required. Furthermore, a user quite naturally will tend initially to define his needs in a form he has customarily employed or with slight improvements and to conceive of using his existing system with little or no modification. In principle, however, it is clear that in at least some instances far greater improvements and benefits can accrue if a user employs data products significantly different from those he has been accustomed to and makes significant modifications to his existing system to accommodate and use the unaccustomed types of data products. User needs can be expressed very differently and there will be strong influences on the sensors and on the data system which can best serve a user. Within the present program, the structure for system modification can be improved. At present, NASA operates what properly can be termed an experimental data-acquisition (not utilization) system in which NASA responsibility terminates when system-corrected, formatted data are made available at GSFC and at the EROS center in Sioux Falls. A user has the responsibility to conceive and develop data utilization within the overall applications program. This compartmentalization has obvious shortcomings. Now that the capabilities of the GSFC and EROS data centers have been demonstrated, user needs can and must be defined in far more detail than has been possible heretofore. At this stage in the program, users need to formulate experimental programs for utilization of data at the same level of detail and completeness at which NASA has formulated the program for data acquisition. In summary, much more refined definition of user needs is required and new mechanisms must be evolved to bring about essential interaction among the sensor, platform, data, and user discipline communities. An important contribution to the solution to this problem can be made by carrying out the type of complete pilot operational applications experiments that are presently under consideration by NASA and by some user agencies.

POTENTIAL BENEFITS

Until now, it has been necessary to base benefits on presently available types of data employed in current utilization systems. Benefits thus formulated are substantial enough to make the program worthwhile. In some instances, however, substantially greater benefits may be derived from user applications when a reciprocal optimization of system structure and data type is attained.

ACHIEVING POTENTIAL BENEFITS

PRELIMINARY SYSTEMS ANALYSES

There is now in operation an acquisition and dissemination system designed to make space data available for experimental purposes. Also, fully operational systems exist for conventional applications. It is vitally important that an acquisition and dissemination system maintain continuity of available experimental data and that system capabilities be upgraded as successive generations of experiments reveal needs and opportunities for modification and extension. As suggested previously, it is necessary that programs be shifted increasingly in the direction of pilot operational applications experiments to direct attention more and more towards the data-utilization part of the overall system.

If a complete operational system for data acquisition and utilization during the 1980's is intended, the design should be started immediately. The design will almost certainly be modified on the basis of results of successive generations of experiments. However, the process of designing an overall system must begin now in order to uncover what the spacecraft designers call interface and procedural problems. These problems become apparent only when the concept includes interactions among all components of the entire system. A first overall-design study is very likely to reveal needs for previously unrecognized research, development, and modification of user systems and procedures.

The time also seems appropriate to make detailed studies of several applications to determine optimum ways of achieving objectives and fulfilling missions. These studies can first describe, in functional and information-flow terms, the way a mission is performed at present and then study progressive changes which may be permitted by the availability of existing or possible types of space data and of data processing.

The systems analyses just mentioned should be supported by earth resource signature studies to indicate what discriminations are physically possible and to refine requirements for sensor performance. In addition, there are needs for development of significant models such as crop canopy, crop phenology, and management decision. All of these will influence systems designs and lead to refined definitions of user needs.

PHASES BETWEEN RESEARCH AND DEVELOPMENT AND OPERATIONAL SYSTEMS

Potential benefits have been experimentally demonstrated within earth observation programs. It is now logical to proceed with pilot operational applications experiments to extend experiments with data utilization. Such experience will be needed to reach a decision on systems which can become operational during the 1980's. Concurrently, research should proceed to improve component technologies for data acquisition and utilization. The major activities which should be carried on are discussed below.

1. Continuity of available spacecraft, aircraft, and DCS data must be maintained so that required experimentation, familiarization, and training can be conducted. As the programs progress, spacecraft, orbits, sensors, and other data sources as well as means of data formatting, cataloging, storage, dissemination, and processing should be upgraded in ways indicated by the results of the experimentation.

2. A number of pilot operational applications experiments should be designed which encompass the activities of users in utilization of data. User objectives which are presently carried out with existing conventional methods and organization, such as crop inventory or yield prediction, should be selected. Each experiment should be constructed by assembling a new team to work in parallel with the existing organization without disturbing their activities. The new team should accomplish the same (or comparable) objectives as the existing organization, using remote sensing data to complement or replace data gathered by conventional means and adjusting organizational structure as appropriate to accommodate the new techniques.

These controlled experiments will provide to the users an understanding of how new methods relate to the old ones and how their organizations should be modified to take advantage of remotely sensed data. Out of this experimentation, evaluation, and comparison will come the information needed to design an operational system.

To the greatest possible degree, pilot operational applications experiments should address the objectives of more than one traditional user organization and thereby indicate the extent to which elements of a new system can serve more than one user.

Related to the design and implementation of the experiments is a strong need to bring user plans and programs to the same state of maturity and completion as NASA has brought plans and programs for data acquisition. This entails much more detailed and structured definition of user needs and determination of consequent effects on data acquisition and utilization.

3. There is a need at this time to proceed with a detailed conceptual design of a complete operational system for data acquisition and utilization carried all the way through to the attainment of some user objective. Proceeding at this time with an initial detailed design is necessary, even though it will almost certainly be modified by results of subsequent experimental programs. Problems arise whenever attempts are made to integrate a large number of diverse technologies into a unified system. Appropriate research and development tasks

and programs must be initiated to provide solutions to such problems when they are discovered within the preliminary design.

4. In order that maximum advantage of new sensing and data technologies be realized, new and improved models of various kinds must be developed for the terrestrial environment. First, models are needed for detecting and discriminating among terrestrial features: for example better signature data are needed concerning plants and soils and must be related to observation models so that sensors can be better specified and so that the degree of performance to be expected can be ascertained and used in evaluating actual performance. Second, since repetitive observations at different times are needed, models should show how terrestrial features may change over a period of time; for example, phenological models of how crops develop during a growing season under a variety of cloud, moisture, temperature and soil conditions. Third, management and decision models for various applications need to be developed and improved.

5. Sensor development should be continued and will be influenced by user needs, signatures, models, and supportive interactions among different sensors. In particular, multispectral scanners need to be refined, proximate sensors for use with DCS need to be developed and improved, and both imaging and non-imaging radio-frequency sensors need to be developed and experimented with.

6. Computer-processing algorithms, systems, and languages must be developed and refined to permit data analyses by a variety of anticipated users, particularly those not well versed in mathematics, programming, or computer-system utilization. These developments will involve interactive data processing systems complete with data access, data display, and programmable terminal capability. Natural language programming systems using processing option lists should be provided with expandable program logic. This will permit user utilization of techniques developed by researchers in the fields of information processing and analysis. In addition, it should provide for incorporation of special purpose hardware developed for special processing applications.

INFLUENCE ON OR BY U.S. SPACE TRANSPORTATION SYSTEMS

Successful operation of ERTS-1, Skylab, and meteorological satellites and extensive experimentation with data from these satellites indicate ways in which earth-observation applications may influence the needs for certain kinds of space transportation capabilities. Although firm specification of space transportation requirements will be reached only after user needs for data and communications are further specified, refined, and translated into engineering terms, the likely form of the requirements is sufficiently clear that it is advisable to initiate new studies and plans for achieving them.

Experimentation with ERTS-1 has determined user requirements that include, for example, swath width, coverage both by time of day and by season, frequency of coverage especially in view of cloud cover, and orbit-inclination effects. These requirements tend to indicate a need for multiple satellites of the ERTS type supported by one or more Synchronous Earth Observatory System (SEOS) platforms. Such multiple-vehicle systems point very strongly to a requirement for

numerous brief manned missions to resupply, adjust, replace, and repair on-board equipment. This type of function can be served by the space shuttle system. Satellites of the SEOS type will require space transportation capable of placing them in required geostationary orbits. Growing needs for more refined sensors (including radar) and for increased refinement in stabilizing and pointing sensors tend toward heavier earth observation satellites, and suggest a need for higher booster thrust. Certain user needs for prompt data access, especially from multiple-user, integrated space systems, can possibly create specialized requirements, for example, tracking and data relay satellites. The Panel supports ongoing NASA studies to determine means for meeting space transportation and other requirements as user needs become more clearly defined in increasing detail.

IMPLEMENTATION ON MANAGEMENT LEVEL

In order that the technical objectives outlined may be accomplished, certain management, organizational, and planning tasks must be done. First, the existing national plan for earth resource survey research, development and implementation* must be extended. It is fairly complete with regard to the development of space systems for data acquisition, formatting, and availability. It needs to be supplemented by an equally complete plan for the development of systems that, using space derived data in conjunction with data provided by traditional services, can produce meaningful conclusions and recommendations for action related to the earth's environment. These systems need to be identified and the agencies for development of the plans should be identified and supported.

Clarification and refinement of user needs and their translation into terms meaningful for systems implementation have already been mentioned and are very difficult. Institutional arrangements must be worked out for identifying agencies to accomplish this difficult task, responsibilities must be clarified, and support must be provided. In addition, needs of individual user communities must be amalgamated to the degree possible so that they can be served by common systems. The Panel supports the joint NASA and user agency plans to implement and demonstrate a small number of end-to-end pilot operational applications experiments as a significant step toward this amalgamation. These experiments also must be supplemented by new institutional arrangements.

A need for substantially increased efforts to develop and improve environmental and management models must be recognized. Responsibilities for these efforts must be delegated and support made available. While observational data and information in themselves are useful, their utility and value are greatly increased when they can be employed in models to predict the effects of human intervention on future events.

Finally, institutional arrangements must be created to resolve the many international problems inherent in the space related elements of an earth observation system.

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*_Transition from a Research and Development to An Operational Mode_. A report by the Interagency Coordination Committee for Earth Resource Survey Programs to the Office of Management and Budget. Washington, D.C., 1973.

SUMMARY

Within the entire scope of space-related data acquisition and data utilization, the Panel on Information Services and Information Processing has concerned itself with the latter domain. In particular, it has addressed the current status of capabilities, performances, perceived needs, and opportunities in the processing, storage, dissemination, and interpretation of data derived from earth-observation satellites. The Panel has focused its study largely on aspects of data handling relevant to applications within the fields of earth resources and environment, including the atmosphere. The systems-specific nature of data handling problems in the field of communications services has led the Panel to exclude such problems from its review and to leave them to the Panel on Uses of Communications* and for later joint consideration. On the other hand, the Panel on Information Services and Information Processing has examined certain aspects of communication that are inherent in the data-handling procedures, current or proposed, for the utilization of earth-observation data.

Review of progress in the field of space-data handling and management since the 1967-68 summer study** and examination of the current status of capabilities and performances reveal that a tremendous amount and variety of experience have been gained and that substantial capabilities have been achieved. The National Aeronautics and Space Administration, the U.S. Department of the Interior, and other participating entities in the public and private sectors have clearly succeeded in bringing about changes of great current and potential import in the fields of earth-resources management and environmental control.

The quantity and quality of data and imagery acquired by the Earth Resources Technology Satellite and by other earth-oriented satellites have exceeded in most respects the expectations and aspirations expressed in the 1967-68 and other studies. However, because the ultimate objective of data acquisition is their constructive utilization in the attainment of socially beneficial and economically productive ends, this achievement has been both gratifying and sobering. The

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*Panel on Uses of Communications. *Practical Applications of Space Systems; Supporting Paper 2: Uses of Communications.* Report to the Space Applications Board, National Research Council. National Academy of Sciences, Washington, D.C., 1975.

**National Research Council. *Useful Applications of Earth-Oriented Satellites: Report of the Central Review Committee.* National Academy of Sciences, Washington, D.C., 1969.

Panel finds that to date, data utilization: (1) does not match performance in data acquisition; (2) does nto realize the potential inherent in the quantity and quality of data acquired, and (3) does not take advantage of available or technolo ically feasible capabilities for data processing, interpretation, and management.

A part of the shortfall in data utilization is attributable to a lack of institutional arrangements that facilitate an efficient flow of information and arrange cooperative efforts for optimum exploitation of data, facilities, and techniques. Related problems and issues, intra-governmental and inter-governmental, public and private, domestic and international, are addressed by the Panel on Institutional Arrangements.* Another part of the shortfall is attributable to funding deficiencies in the several subfields of data utilization. While great emphasis on the development of capabilities for the acquisition of earth-features data was natural and appropriate in the early phases of the space applications program, the Panel on Information Services and Information Processing concludes that both need and opportunity, as well as technical capability, now exist for accelerating progress in effective data utilization. The Panel believes that, while the demonstration of tangible, quantifiable benefits from U.S. investment in space technology has been delayed by the reluctance of normally conservative economic sectors to adopt new methods, increased emphasis on and attention to many aspects of data utilization in pilot or quasi-operational projects can and now should accelerate such demonstration. A major part of the overall problem of realizing the potential usefulness of acquired data is attributable to the inherent great magnitude, the complexity, and the diffuse character of user communities, especially to their multifaceted data requirements, and to a lack of available physical resources and capable personnel for extracting and analyzing relevant information.

*Panel on Institutional Arrangements. *Practical Applications of Space Systems; Supporting Paper 10: Institutional Arrangements*. Report to the Space Applications Board, National Research Council. National Academy of Sciences, Washington, D.C., 1975.

CONCLUSIONS AND RECOMMENDATIONS

GENERAL CONCLUSIONS AND RECOMMENDATIONS

In order to address meaningfully the information handling aspects of the applications of space systems for the 1980's, the Panel on Information Services and Information Processing found it desirable to consider first the overall national program context in which data handling problems must be approached. Without an integrated and dynamic national program for practical experimentation in data utilization, improvements in data processing and information services can hardly be expected to yield significant increases in socioeconomic benefits.

The Panel concludes that the experience gained and the results achieved to date with earth-observation satellites now warrant increased support in several applications fields for studies and practical experiments in preparation for the design of operational systems. Toward that end and with the ultimate objective of realizing sooner and more fully the indicated potential benefits of earth observation satellite systems and data, the Panel submits the following general recommendations.

In earth observation space applications, program emphasis should now be shifted toward operationally-oriented experiments and design.

The national plan for exploitation of space technology in earth observation applications should be revised to achieve the same degree of completeness for data utilization as for data acquisition. It should be extended to include user agency plans and to take into account where possible mature plans for domestic private and foreign governmental sectors.

Data utilization experimental programs for participating and affected user agencies should be formulated at an early date and documented at a level of thoroughness comparable to that which has characterized data acquisition programs.

Adequate resources should be applied to upgrading experimental systems as a basis for planning and executing pre-operational experiments.

A set of pre-operational experiments in the utilization of satellite derived earth resources and environmental data should be selected in 1974-75 and conducted within the 1976-80 period.

A preliminary design study of a complete and fully operational multiple-user applications system should be initiated in 1975 in order to identify those systems, mission, and interface problems which must be solved in order to avoid delay and interruption of data flow. In particular, at an early date multiple-user needs must be clearly defined, possible conflicts identified, and acceptable compromises examined, especially with respect to sensor complement, orbit, and implications for mission planning, control, and procedures.

Timely and adequate budgetary authorization and appropriations should be provided in order to assure continuity in acquisition and utilization of earth observation data. Such continuity is essential for progress toward the design and development of operational systems.

Within the period 1975-80, or until operational public or private systems are available, the national program should permit and, within reason, facilitate quasi-operational use of then-existing experimental systems for applications which are in the national interest and for which near-operational capability has been demonstrated. The cost-reimbursable basis of such use will need to be examined.

The Panel concludes that design and development of systems for data acquisition, processing and interpretation techniques can be advanced significantly by more precise definition of user needs and more careful translation of needs as defined into systems design parameters. Recommendations based on this conclusion follow:

Program studies should be initiated with the explicit objectives of achieving precise definitions of user data needs in various applications areas and translating defined needs into systems parameters.

Necessary institutional arrangements should be created to refine definition of user needs, to evaluate the impact of user needs on space systems, and to identify areas of common needs among users.

Optimum methods of satisfying user needs may involve selective use of data from aircraft and ground sources to complement data from space systems. This would avoid the problems associated with handling the very large volume of data which would result if space high resolution data alone were used.

It is recommended that alternative ways to achieve user objectives using data from various sources, be analyzed to determine optimum methods, and subsequently, that the effect on user activities of integrating new (and previously unavailable) data be studied.

Only the simplest environmental and resources problems are solvable using data from a single source. To solve most problems, data or information will be required from existing sources such as maps or statistical records, as well as new data and information from aircraft and from spacecraft. Data relayed by satellite from numerous ground sensors may be needed as well. These data will have different formats, information content, rates of arrival, perishability, and other distinguishing features. To bring all these data together, in such a manner that they jointly provide needed information, requires solution of the very difficult and distinct technical problem of integrating disparate data. The Panel concludes that the problem of generating useful information from disparate data is not sufficiently recognized and is not receiving the attention that it requires.

The Panel recommends that NASA and the user agencies more explicitly recognize the existence of the disparate data problem and provide resources for work upon it.

DATA HANDLING CONCLUSIONS AND RECOMMENDATIONS

Data acquired by current earth-oriented satellite systems have been processed and distributed in varying degrees by various data centers in the U.S. including Goddard Space Flight Center (GSFC), National Environmental Satellite System (NESS), Earth Resources Observation System (EROS), and by Canadian and Brazilian centers. These data have been considered by the Panel in terms of the following major attributes of significance to the user:

Type of data (visual, infrared, thermal infrared, microwave, active, etc.)

Quantity (area, swath width, etc.)

Quality (resolution, accuracy, dynamic range, etc.)

Format (tape, film, prints, scale, grid, etc.)

Frequency of coverage

Timeliness of acquisition

Timeliness of delivery or access

Compatibility (with other multiple-source data)

Continuity of data flow.

The Panel finds that while great volumes of valuable data have been acquired and while genuine and, to a commendable degree, successful efforts have been made to process and distribute those data to experimenters and users, there are significant needs and opportunities for improvements to maximize the effectiveness and benefits of space-data utilization during the 1980's. In particular, improvements are necessary and possible in the following domains:

Responsiveness of data acquisition systems to user needs

Quality and utility of data delivered to users

Access to data by users

Means for utilizing data.

Conclusions and recommendations are given in each of these areas. Recommendations are not addressed to any one agency nor exclusively to governmental agencies; some needed development and services should come from the private sector.

Responsiveness of Data Acquisition Systems to User Needs

The Panel concludes that program results to date indicate a need for additional types of sensor data.

> *It is recommended that sensor development be continued and take into account an increasing understanding of signatures, user needs, and data handling requirements. Special attention should be given to accelerating the development of microwave imaging and non-imaging sensors, to improving ground sensors and data handling for use with the data collection system (DCS), and to increasing the number of multispectral scanner channels, particularly thermal channels.*

In planning missions to take care of the needs of potential users, the Panel concludes that many remote sensing requirements for differing disciplines can be satisfied by sharing the time of nearly identical sensor systems. In addition, the large payload capabilities planned for the U.S. space transportation system will allow simultaneous orbit of multiple-sensor systems even though some have partially conflicting operational requirements.

> *It is therefore recommended that effective automatic techniques for operational mission planning, scheduling, and analysis be developed to assure the most effective utilization of space-borne sensors which can be shared among multiple users.*

Quality of Data

The Panel concludes that the present practice of geometric correction of data of the ERTS-1 type by analog processing significantly limits throughput and degrades data quality. The Panel thus recommends:

Available advanced techniques for all digital processing and dissemination of sensor data should be applied to preserve data quality and to increase throughput at the processing center.

A prototype facility for all-digital geometric correction of ERTS-1 data should be developed to demonstrate the operational feasibility of high-throughput geometric correction and registration. When proven successful, this facility can be utilized to off-load and eventually to replace the existing ERTS-1 correction facility and thus can result in substantial improvement in data quality (resolution and accuracy) and throughput.

The Panel concludes that in order to avoid multiple sensor-data geometric calculations, the accuracy of these calculations should be commensurate with the the most stringent user requirements, within user physical facility limitations. For example, automatic change discrimination and utilization of temporally registered scenes in signature classification require registration of successive scenes to within fractional picture element accuracy to maximize interpretation performance (without additional geometric modification).

It is recommended that operational registration of single sensor multiple-temporal scenes be accomplished simultaneously with geometric correction. This could be done by geodetically correcting a reference scene using geodetic control points and then geometrically correcting later scenes to the reference scene geometry using control points from the reference scene. Thus, although geodetic accuracy of scenes is determined by the accuracy of geodetic control points, successive scenes of the same area will be inherently registered to much higher accuracy.

The Panel concludes that frequency of coverage by some earth-observation sensor systems is inadequate for certain applications and therefore recommends that:

Economic trade-offs of alternative operational methods for achieving more frequent coverage should be investigated. Uses of multiple satellites, single satellite sensors with increased swath width, and synchronous satellites should be considered.

Studies of requirements on the U.S. space transportation system should be continued to accommodate consideration of more frequent coverage, heavier payloads, use of synchronous orbit, and other factors.

Access to Data by User

The Panel concludes that there is a need for improved balance between centralization and decentralization of data handling functions based upon users' common needs in order to achieve economies in data processing and dissemination and to assure greater uniformity of data products. Thus, it is recommended that:

Basic data formatting and corrections common to all users of data from any specific space-borne earth observation system should be accomplished centrally rather than be required of each user separately.

User-specific processing requiring utilization of locally available correlative data, trained personnel, and user proprietary interpretive techniques or models should be accomplished in decentralized facilities.

A master catalog of all space-derived earth observation data, cross-referenced on common indices, should be generated and maintained in a central library, with copies distributed to decentralized facilities.

Data should be provided by a centralized processing facility on digital tape, radiometrically calibrated but geometrically uncorrected, with the geometric correction coefficients for a standard product included on the tape. Algorithms should be readily available for conversion of correction coefficients to nonstandard formats and map projections at user-specific facilities.

The Panel concludes that timeliness of access to acquired data is currently a barrier to effective utilization of such data for several earth resources and environmental applications. Therefore, the following are recommended:

Feasibility and trade-offs should be investigated for correction of data on-board earth observing spacecraft to enable direct readout by users.

Insofar as feasible, intermediate manual steps should be eliminated in the raw-data correction and reformatting processes by using all-digital processing techniques for generating computer-compatible tapes.

The central master data center and the central ground receiving station should be at the same location and at a position providing maximum land coverage within the continental U.S. Receiving stations and primary data processing centers also should be co-located, where feasible, in regional and foreign centers.

The Panel concludes that acquired earth observation data are insufficiently available in a readily retrievable form suitable for specific user requirements, and that efficient application of space-detected observations often utilizes data from multiple observation systems. The Panel therefore recommends that:

Methods and computer programs for indexing high-density storage should be developed to provide ready retrieval in a convenient coordinate system.

Efforts should be vigorously pursued to achieve a greater degree of record format compatibility among data derived from or by different space-borne sensor systems.

The Panel concludes that access to data is required at several stages in the progressive processing and intepretation of earth resources and environmental data owing to the diversity of user applications and to the varying levels of sophistication among users.

It is recommended that provision should be made at the central facility for user access to data in computer-compatible format as well as at decentralized facilities where products represent different stages of processing and interpretation.

The Panel concludes that, despite the tremendous leverage afforded by modern digital techniques for data and image processing and analysis, the human eye and brain are a powerful combination for rapid detection, discrimination, selection, and interpretation of natural and man-made features in earth imagery. Indeed, for many ultimate users, human photointerpretation will for some time remain the only available means of selecting and interpreting such imagery. This means must be neither foreclosed nor minimized.

It is recommended that steps should be taken to provide both centralized standard and decentralized custom photocopy services, with emphasis on manipulation and control of grey scales and false-color tones so as to optimize visual detection and discrimination of specific types of earth resources and environmental features on black and white and on color-matched photoprints and transparencies.

The Panel concludes that current high-speed, fast-access and mass-storage capabilities do not match projected user requirements.

The Panel therefore recommends that emerging advanced techniques for high-density and high-rate data storage, such as holographic memories, magnetic bubble memories, charge-coupled devices, and high-density magnetic memories, should be investigated for possible adaptation to data storage in spacecraft and as media for data ground transmittal and storage.

The Panel concludes that an appreciable delay between data acquisition and data availability to users is due to the time required for transmission of received data to the centralized correction facility and to the time required for transmission from the centralized facility to the decentralized facilities and to users. The following are therefore recommended:

Sensor-data and processed-data communications link requirements should be studied in terms of bandwidth requirements and costs as a potential replacement for conventional transport of mass-storage media.

Direct transmission to local terminals can give users at remote sites access to catalog and data in centralized archives and should be evaluated with respect to communication link requirements and costs and projected remote-terminal costs.

The Panel concludes that any earth observation system will acquire some data and information which for some periods of time should be proprietary and receive only limited distribution. When the data are distributed widely, care must be taken to make them available simultaneously to all interested segments of the user community. A typical historical example is the periodic crop-yield estimates of the U.S. Department of Agriculture. Confidentiality of some data and information in an earth observation system conceivably can impose significant requirements on the system which cannot be foreseen in any detail until the degree of confidentiality is defined.

It is recommended that needs for confidentiality and restricted distribution of some data and information in an earth observation system should be formulated so that the impact on the data-distribution system can be determined.

Means for Utilizing Data

The Panel concludes that the full potential of space-derived earth observation data can be realized only when two types of scientifically valid models are available. One type uses environmental data in predicting dynamic phenomena. The other type uses observed data in inferring the existence of features or conditions not directly observable. Since there is a dearth of such models, it is recommended that:

Development and testing of predictive and inferential models should be given increased emphasis.

Necessary institutional arrangements should be created to accomplish the development of new and improved environmental predictive and inferential models.

The Panel concludes that stages of development are not very uniform for various elements of automatic classification of space data. Theory and programs

are relatively advanced for ERTS-1 multispectral data classifications. However, only a primitive state of development has been attained for preprocessing and feature extraction methods that extend classifications over different geographic locations without invoking new training sets, corrections for sun angles, viewing angles, and other factors. Research and development are also needed in temporal classification, in classification based upon spatial and polarization target and sensor characteristics, and in the integration of data from a variety of ancillary sensors and sources. Significant increases in interpretation and classification capabilities will result from further development of these methods.

The Panel recommends that significant resources be devoted to the further development of automatic classification based on spectral, spatial, temporal, polarization, and multiple-sensor effects.

The Panel concludes that, as the program proceeds with more applications experiments, the need is increasing for greater transferability of data processing and analysis within computer programs.

It is recommended that, to the degree possible, pattern recognition and data processing computer programs should be expressed in commonly usable and transferable languages and documentation.

The Panel concludes that effective development and improvement of sensor systems, data processing, and interpretation require more and better spectral, spatial, polarization, and temporal signature data than are now available.

The Panel recommends programs for determination of spectral, spatial, polarization, and temporal signatures should be intensified to provide inputs required for development and improvement of sensors, data processing, and interpretation.

The Panel concludes that the program for observation of earth resources has brought about measurable changes in methods for managing and effectively utilizing resources. However, the information now being used to assist in these tasks comes in formats new to many potential users. The availability of this information on a routine basis and the possibility of acquiring from a host of sources broad information heretofore unattainable place a burden on both the developers and the users of the system. To be able to handle and effectively to utilize the information, system developers, resource managers, and planners at all levels must be informed about the availability of the information and trained in its use.

The Panel recommends that education and training in the new and sophisticated technologies that are being introduced into user applications of space systems should be encouraged strongly and in a formal way in the programs of NASA, USGS, and the user agencies. Then, such education should become increasingly available in university curricula and as training at both the managerial and technical levels for personnel within the user community.

APPENDIX

SENSOR GEOMETRIC CORRECTION

Procedures for Imaging-Sensor Geometric Correction

Geometric distortion arises in sensor data because of sensor internal geometric nonlinearities, spacecraft platform attitude motions and ephemeris, earth curvature and rotation, and viewing aspect geometries. Many of these distortion sources can be determined and precisely calibrated, for example, earth rotation and viewing aspect geometries. Others, such as spacecraft attitude and ephemeris, are semi-random and can be measured only to varying degrees of accuracy. In addition, desired map projection and scale may differ substantially from the sensor viewing geometry. Geometric correction can be divided into two parts: distortion calculation and distortior correction. Distortion calculation incorporates all measurements and calibrations of distortion components and the desired map projection geometry to determine the displacement of each picture element from its true (or desired) location in the received image. The accuracy of picture element displacements is determined by the accuracy of semi-random measurements. This accuracy can be improved by incorporation of further distortion measurements, in particular, features within the image called control points, whose true locations are known. If control points are located from maps they are called Geodetic Control Points (GCP) and geodetic accuracy of the order of accuracy of the GCP can be obtained within the image. If control points are located by correlation with an image of the same area taken at a different time, they are called Registration Control Points (RCP), and relative geometric accuracy (registration) between the two temporally displaced images is of the order of the accuracy of the correlation procedure and thus depends on the number of control points utilized. Since the distortion at each picture element is a complex function of location within the image, precision calculation of the displacement at each picture element is an inordinately time-consuming process. Consequently, displacement is calculated precisely only on a selected grid of points within the image and displacements at all other points are determined by interpolation of the displacements on this grid. By selection of the grid spacing, arbitrary modeling accuracy can be achieved. Thus, image distortion is completely described by a set of interpolation coefficients. These interpolation coefficients define the distance each picture element sample must be moved to place it in the desired map coordinate system and are specific to the map projection and scale. Conversion of the coefficients to represent other map projections or scales are trivial algebraic exercises.

The second part of geometric correction includes moving the sensed picture element intensities to their desired locations via the displacement previously calculated. Equivalently, at each location (line or sample) in the desired corrected projection system, the location of the corresponding sensed picture element intensity is calculated. In general, the desired location will not coincide exactly with the locations of the sensor samples. Consequently, the surrounding sensed sample intensities are interpolated at the desired location. This interpolation procedure must be performed at every point in the output precision image and consequently can represent the dominant load on the entire geometric-correction process. However, current techniques of utilizing special purpose digital equipment (hard-wired algorithms) with minicomputers for control have reduced this problem to insignificant proportions relative to generation and duplication of outputs such as Computer-Compatible Tape (CCT), film, and High-Density Digital Tape (HDT).

Provision for Decentralized Geometric Correction

Sensor data (for example, from the ERTS-1 multispectral scanner subsystem) are required by users in numerous map projections, scales, and formats. Geometric manipulation of sensor data should be performed once, at most, since computer round-off and approximation errors compound in successive steps. For all sensor data at the centralized facility to be corrected to all the various forms needed by users requires several different geometric-correction passes through each frame of data and consequently produces substantial logistics and throughput problems.

On the other hand, all data (for example, spacecraft attitude and ephemeris, sensor dynamics, nonlinearities, and boresighting, and registration control-point libraries) required for determining geometric distortion in the sensor data are available at the centralized facility. The process of calculating the geometric distortion is much the same for all users and results in geometric correction coefficients which users can easily modify algebraically for any desired map projection, scale, or format.

Geometric manipulation of sensor imagery by digital means at high throughput is relatively inexpensive, if the distortion coefficients are given and if inexpensive minicomputers and simple hard-wired algorithms are available. The cost of acquisition and duplications systems with large throughput and output renders insignificant the cost of geometric-image manipulators.

The most cost-effective implementation of an image correction facility takes place as shown in Figure I. The centralized correction facility performs all operations common to all data users, namely, data reformating, radiometric calibration, maintenance of control-point library, distortion calculation, and digital transmission-medium formatting. Data are then transmitted digitally to decentralized (user-specific) facilities in radiometrically corrected standard format with all geometric-correction coefficients included with the geometrically uncorrected data.

The decentralized facility then modifies the geometric-correction coefficients appropriately, if desired, and generates a digital tape corrected and formated to user requirements. The decentralized facility then generates and duplicates user products (tape or film) for dissemination.

The centralized facility also has an image-correction processor for generation of digital imagery in standard map projection. The uncorrected tapes containing the correction coefficients are stored in archives for later use, if required.

A suggested implementation of the concept of an interim system for handling digital data from ERTS-1 (that is, pre-operational) is shown in Figure II. The centralized NASA Data Processing Facility transmits geometrically uncorrected tapes containing the correction data to the EROS center for geometric correction and output processing generation and dissemination. A prototype image correction processor can be developed at the NASA Data Processing Facility.

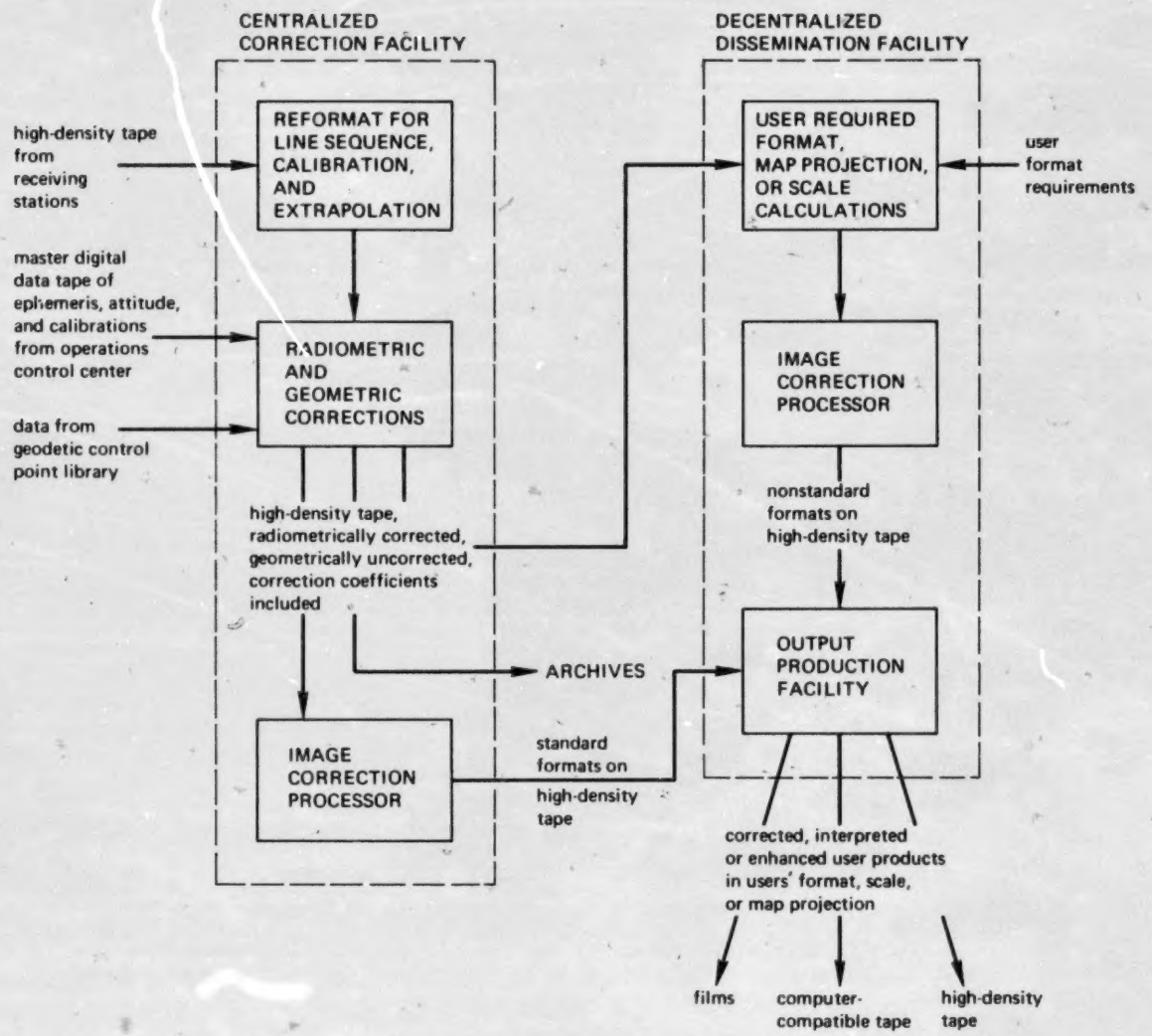

FIGURE I CONCEPT OF RECOMMENDED FACILITY FOR CENTRALIZED CORRECTION AND DECENTRALIZED DISSEMINATION OF ERTS-1 DATA

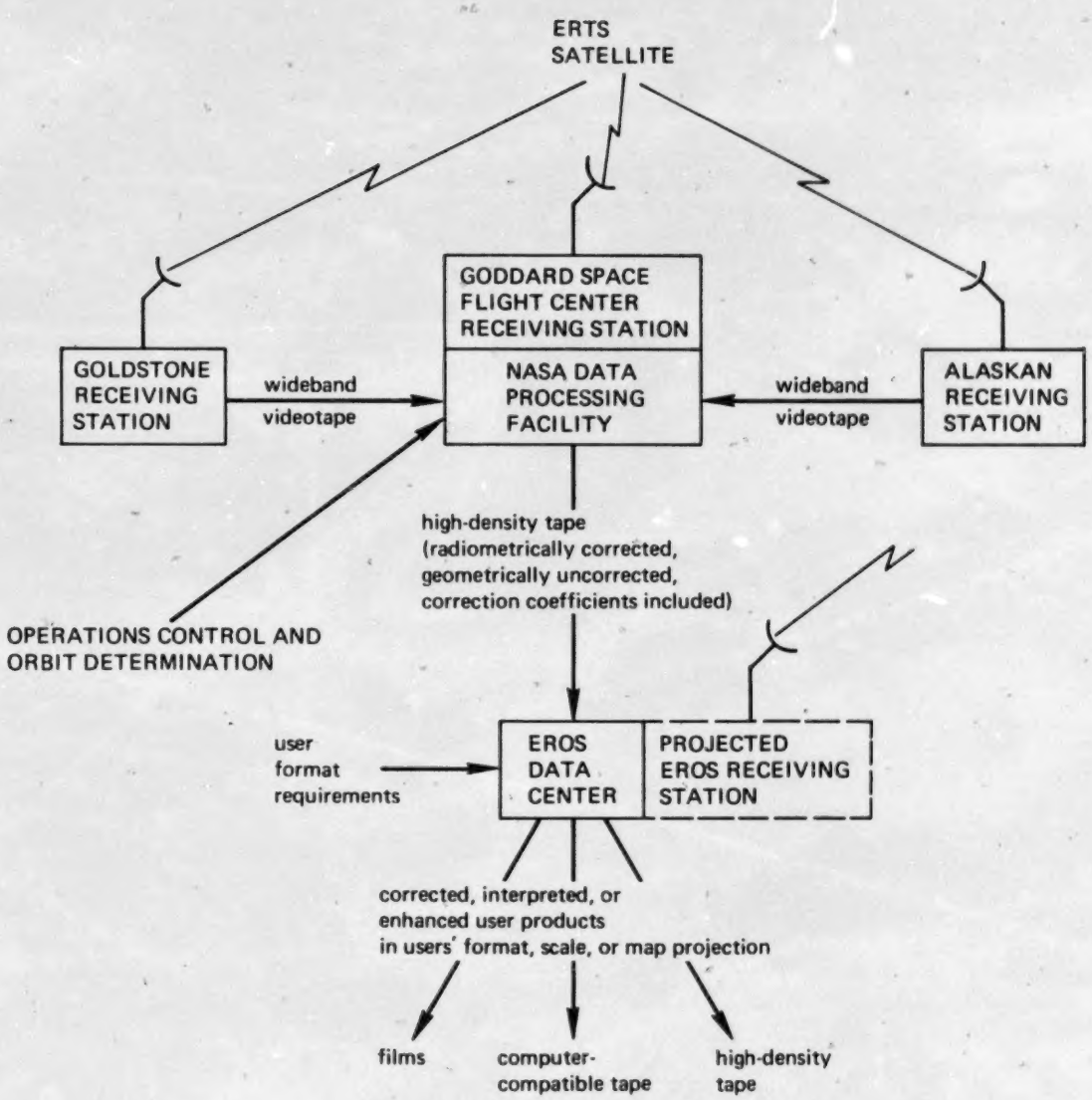

FIGURE II CONCEPT OF RECOMMENDED INTERIM CENTRALIZED FACILITY FOR HANDLING DATA FROM ERTS

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